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Sea surface temperatures of the Leeuwin Current in the Capes region of Western Australia: potential effects on the marine biota of shallow reefs

M B Westera [1,4], J C Phillips [2], G T Coupland [1], A J Grochowski [1], E S Harvey [1] & J M Huisman [3]

[1] School of Plant Biology (and Centre for Marine Futures)
University of Western Australia 35 Stirling Hwy, Crawley, WA 6009.

[2] CSIRO Marine and Atmospheric Research
Private Bag No 5, Wembley, WA 6913

[3] Murdoch University, School of Biological Sciences and Biotechnology
South Street, Murdoch, WA 6150,
and Western Australian Herbarium, Department of Environment & Conservation,
George St., Kensington, WA 6151, Australia.

[4] SKM Australia, 7th Floor, Durack Centre, 263 Adelaide Terrace, Perth, WA 6001

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Abstract

The Leeuwin and Capes Currents have been shown to influence marine assemblages along the Western Australian coast. In this study we examined potential relationships between the sea surface water temperature (SST), as a consequence of the Leeuwin and Capes Currents, and the distribution of fishes and algae. Data were collected from locations that spanned the temperate Capes coast (33°30' to 34°25'S). Fish assemblages were measured using diver operated stereo-video and stereo baited remote underwater video. Algae were harvested from quadrats. Mean SST at the most southerly region was 18.5°C while regions on the west coast of the Capes were generally one degree warmer.

Seventy three species of fishes were recorded belonging to 36 families. Two species were classified as tropical and one species as sub-tropical (*Cirrhilabrus temmincki, Plectorhinchus flavomaculatus* and *Choerodon rubescens* respectively). Forty four percent of species from the Capes were classified as either tropical, subtropical or subtropical-temperate. The remainder were of temperate or widespread distributions.

Two hundred and five species of algae were recorded belonging to 49 families. All species were regarded as temperate with the exception of the geniculate red alga, *Rhodopeltis borealis.* Eleven range extensions were recorded for algae: two were southward of the current known range (*Champia compressa* and *Rhodopeltis borealis*) and the remaining nine were northward or westward extensions.

Within the 120 km of the Capes coast studied, regions with warmer waters did not have higher abundances of fishes of tropical, subtropical or subtropical-temperate origin than cooler waters. However, the most southerly region was different in terms of algal assemblage structure with water temperature the most influential of environmental variables, relative to exposure, substratum and depth.

The large proportion of fish species with tropical, subtropical and particularly subtropical-temperate distributions recorded is consistent with other studies and may be due to the influence of the Leeuwin Current. The range extensions for algal species may be due to the effects of the Leeuwin and Capes Currents but may also be due to the paucity of algal collections from some parts of the Capes region. Other factors such as topographic complexity, depth and other habitat structure variables may also be influencing marine assemblages. The findings of the work support the notion that there is a large transition zone between biogeographic provinces within which the Capes region is positioned.

Keywords: Leeuwin current, Western Australia, Capes, fishes, algae, reefs, water temperature

Introduction

Oceanic currents have the potential to influence dispersal and distribution of marine species (McGilliard & Hilborn 2008) sometimes across thousands of kilometres (Shanks *et al.* 2003). The Leeuwin Current (LC), which originates in the tropics, carries warmer waters southwards past the coastline of Western Australia and has been shown to influence the distribution of fishes (Hutchins 1991; Ayvazian & Hyndes 1995), corals (Hatcher 1991), lobster (Caputi *et al.* 1996) seagrasses and algae (Walker 1991). A consequence of the LC is that the marine biotic assemblages of south western Australia contain species that extend further southward in their range than would otherwise be possible. Although the poleward moving LC is dominant along the west coast, it is met by the Capes Current (CC), a cool equatorward counter current near the south west corner of Western Australia (Pearce & Pattiaratchi 1999) that may also influence the distribution of marine biota.

We propose that the unusual oceanographic conditions in the Capes region (Busselton to Augusta) Western Australia, which result from the combined effects of the LC and the CC, influence the distribution of marine flora and fauna. We compare distributions of fishes and algae that were recorded in the Capes region, to known distributions to assess the proportions that are regarded as more tropical in their range. We also investigate variations in the distribution of species within the Capes region that may be due to these currents. The paper forms part of a larger study to establish a benchmark of data on fishes and algae in the Capes region, and to assess changes in these over time in proposed, and then gazetted, sanctuary zones. Consequently the design, the location of sites and the data collection methods were predefined as part of the broader project.

This paper provides: a summary of the information on the Leeuwin and Capes Currents in the Capes region (more detailed accounts are provided elsewhere in this special issue) and how they may influence marine biota; a description of other factors that may influence the structure of marine biota in the Capes region; a summary of some previous investigations of marine biota, the influence of the LC and how these relate to the Capes region; and an examination of relationships between sea surface temperatures, as a consequence of the LC and CC, and marine biota in the Capes region of Western Australia from a comprehensive survey of reef communities.

The Leeuwin and Capes Currents

The LC is unusual as unlike other eastern boundary currents, it transports warm tropical waters polewards, and simultaneously inhibits upwelling (Pearce 1991). It flows from Exmouth, Western Australia, past Cape Leeuwin and on to the Great Australian Bight (Maxwell & Cresswell 1981; Cresswell & Peterson 1993; CSIRO 2001) with an influence as far as Tasmania (Ridgway & Condie 2004). The waters are low salinity (Cresswell & Peterson 1993) and relatively nutrient poor (Pattiaratchi 2006). The LC is narrow (< 100 km wide) and shallow (< 300 m deep) (Pattiaratchi 2006) by global standards for a major current system and flows at a relatively high velocity (0.1–1.0 ms^{-1}) (Smith *et al.* 1991; Cresswell & Peterson 1993). It is seasonal, with higher flow during autumn, winter and early spring than in summer (Pearce 1991) and with fluctuations in the rate of flow linked to variations in wind stress (Godfrey & Ridgway 1985; Smith *et al.* 1991). The southerly flow of the current changes direction at Cape Leeuwin, turning east and then continuing into the Great Australian Bight. Downwelling of the LC results in low nutrients and consequently low levels of primary production (Hanson *et al.* 2005; Pattiaratchi 2006) which in turn influences fisheries (Gaughan 2007).

The CC is a wind-driven, high salinity, cool water current that flows equatorward, is strongest from Cape Leeuwin to Cape Naturaliste, and widens to extend northwards beyond Perth (Pearce & Pattiaratchi 1999). In summer, the LC is met in the Capes region by waters of the CC, which occupy most of the continental shelf and consequently inhibit the flow of the LC across the shelf (Cresswell 1991; Pearce & Pattiaratchi 1999; CSIRO 2001). In the winter months, the CC does not flow, allowing the LC to flood across the continental shelf to the coast to warm the inshore waters. The shallow waters in Geographe Bay, however, remain cool due to loss of heat to the atmosphere (CSIRO 2001). Due to the presence of the CC, oceanic waters of the Capes region undergo a different seasonal regime compared to other waters influenced by the LC.

Water temperatures at Cape Mentelle, in the central part of the Capes region, range from approximately 21°C in March / April to 17.5°C in September (Pearce & Pattiaratchi 1999). The peak temperatures are associated with a weakening of the CC. The water temperature range at Cape Mentelle, of approximately 4°C, is less than the 7°C range in the Perth region (Pearce & Pattiaratchi 1999).

The LC has been shown to influence marine biota by providing warmer waters for more tropical species (Gopurenko *et al.* 2003; Hutchins 1991; Maxwell & Cresswell 1981); lowering temperature range on inshore reefs as has been shown at Cape Mentelle (Pearce & Pattiaratchi 1999); and transporting the larvae or adults of various species (Caputi *et al.* 1996). In contrast the CC influences the region by transporting cooler waters from the south and associated marine species (Pearce & Pattiaratchi 1999), although the influence of the CC may be less than the LC as it is not the dominant current and flows only in the summer.

Other factors that structure marine reef communities of the Capes region

The structure of marine reef communities is influenced by many factors in addition to currents, such as wave energy and exposure, depth, substratum type and topographic complexity (rugosity or vertical relief of reefs). Any investigations into the effect of currents and water temperature on marine biota should also consider these smaller scale influences.

Cape Naturaliste, in the north of the Capes region, has been described as being a high energy region, when compared with other exposed regions on the Australian coast, with high flow bed shear stresses due to the LC and storm impacts from the South West (Hemer 2006). High shear stresses would likely influence the recruitment and growth of benthic macroalgae and associated fish communities.

The Capes region is dominated by limestone and granite reefs of varying depths, levels of topographic complexity and wave exposure. Kendrick *et al.* (2004) showed that variation in the macroalgal assemblages in the Capes region was driven by whether the substratum was limestone or granite, depth was <10 m or 10–20 m, and whether the reef was high relief (>2 m), or low relief. A study by Toohey (2007) in the Hamelin Bay region of the Capes showed that algal assemblages were structured by different levels of topographic complexity, which influenced light, water motion and sediment cover. Also at Hamelin Bay, Harman *et al.* (2003)

recorded differences in fish assemblages between limestone and granite reefs, and between high and low relief reefs. High relief reefs had larger numbers of fish species than low relief reefs. The kelp *Ecklonia radiata* was more dominant on low relief limestone reefs but was less dominant on granite reefs and high relief limestone reefs. Ayvazian & Hyndes (1995) noted that surf zone fish assemblages in the Capes region were influenced by the presence of seagrasses or patch reefs.

Differences among regions in the current study, or larger scale differences in marine biota that may be attributable to the Leeuwin and Capes Currents, would also very likely be influenced by the aforementioned, and other, structuring processes.

Previous studies of marine biota and the influence of the Leeuwin and Capes Currents

The LC has been shown to influence the distribution of fishes and nearshore fisheries along the Western Australian coast (Lenanton *et al.* 1991). Ayvazian & Hyndes (1995) noted an influence of the LC on surf zone fish assemblages. Lower numbers of species on the south coast and an absence of tropical species were attributed to the reduced influence of the LC compared with the west coast.

Strengthening of the LC flow in March coincides with recruitment of tropical fish species at Rottnest Island (Hutchins & Pearce 1994) which, at a latitude of 32°S, is a temperate marine environment and is approximately 200 km north of the Capes region. Hutchins (1991) recorded an autumn / winter influx of juvenile tropical fishes at Rottnest Island in areas that are influenced by the LC. The most likely source of breeding stocks was thought to be the Houtman Abrolhos Islands 350 km to the north and larval durations of the species observed were sufficient to cover this distance at the LC rate of 2 to 3 knots. Approximately 17% of reef associated nearshore species were classified as tropical.

Gopurenko *et al.* (2003) recorded mud crabs (Portunidae; *Scylla* spp.) in SW Australian estuaries 1000 km south of their recorded distribution and linked this to a recruitment event enhanced by the strong 1999/2000 LC.

A number of studies have investigated the influence of the LC on commercially important fisheries. Low levels of finfish production in the region are primarily due to the low nutrient waters of the LC (Caputi *et al.* 1996). However, the LC has a positive influence on post larval settlement of the western rock lobster (*Panulirus cygnus*) (Phillips *et al.* 1991). When the LC is strong the settlement of puerulus generally occurs 2° further south than in years when the LC is weak (Caputi 2008).

The influence of the LC on finfish is not consistent among species. It has been shown to have a negative effect on larval survival of pilchards (*Sardinops sagax neopilchardus*) but a positive impact for whitebait (*Hyperlophus vittatus*) (Lenanton *et al.* 1991; Caputi *et al.* 1996; CSIRO 2001). In contrast it has been suggested that the CC influences the commercial salmon fishery in the SW region by providing a conduit of cooler water that allows them to migrate around Cape Leeuwin and up the west coast (Pearce *et al.* 1996). Gaughan *et al.* (2007) suggested that the LC system most likely contributes a net negative impact on success of teleost eggs and larvae on the west coast of Australia. Larvae are likely to be trapped in warm core eddies that form from the LC and would contribute little to nearshore recruitment.

Some tropical species of coral that are able to tolerate cooler conditions form isolated colonies in the Capes region, including species of the massive corals *Favites, Goniastrea* and *Turbinaria* (Veron 2000; Veron & Marsh 1988). Fourteen species of coral from seven genera were previously recorded in seagrass beds and among small macroalgae in Geographe Bay in the Capes region (Veron & Marsh 1988).

Patterns of algal distribution are the result of dispersal, settlement and recruitment, and growth, (Walker 1991) and the LC may affect any or all of these processes. Effects of the LC on the marine flora are less detectable, however, than those on the fauna and may be due to limited habitat availability and/or limited dispersal distances of algae (Walker 1991). In their study of the algae of Rottnest Island, Huisman & Walker (1990) found that most species were of temperate affinity and only sporadic occurrences of 'tropical' species were recorded, which suggests that water temperature is important. They suggested that the variable strength of the LC could account for the relatively few 'tropical' algae at Rottnest Island (Huisman & Walker 1990).

Drift algae have greater dispersal potential than species that rely solely on spore dispersal. Species of *Sargassum*, for example, are often positively buoyant once detached from the substrate and viable plants could be transported into suitable habitats on the south coast by the LC (Phillips 2001). Walker (1991) suggested that the presence of *Sargassum decurrens* at Rottnest Island may be the result of the southerly flowing LC, as this species has a northerly distribution in Australia.

When kelp-associated algal distributions were examined over a wide geographic area, Wernberg *et al.* (2003) found that distinct regional algal assemblages could be discriminated, with some overlap between adjacent regions. While regional differences were evident, it was found that local- and small-scale processes also contributed significantly to kelp-associated algal assemblages (Wernberg *et al.* 2003). The kelp *Ecklonia radiata* decreased in importance as a canopy species moving south, and may be the result of decreasing water temperature (Wernberg *et al.* 2003 and references therein).

The oceanographic conditions in the Capes region due to the LC and the CC may therefore influence the marine biota of nearshore reefs and, based on the findings of previous studies, water temperature and larval transport are the factors most likely to influence these biota (Lenanton *et al.* 1991; Phillips *et al.* 1991; Walker 1991;Caputi *et al.* 1996; Gopurenko *et al.* 2003). However other factors such as depth, exposure and substratum type will play a part in structuring the marine communities. This paper uses data from a benchmark study on nearshore marine reef communities of the Capes region to investigate the potential influence of the LC on fish and algal assemblages of shallow reefs (10 to 20 m). Specifically: the distributions of species are compared with known broadscale distributions; and then relationships are tested between biological (the composition of fish and algal assemblages) and physical variables (water temperature, substratum type, depth and exposure) at a regional scale within the Capes.

Methods

Site selection

The data used in this paper form part of a larger study in the Capes region to set marine benchmarks and to evaluate the effect of sanctuary (no-take) zones on marine reef assemblages. Four regions from that study were included in the current paper with the aim of examining the effect of the LC. These were Naturaliste, Freycinet, Hamelin and Flinders Bay; with four sites at each region (Figure 1) that span 120 km of coast from 33°30' to 34°25'S. Data were collected in summer of 2005–06.

Reef sites were selected to be representative of the broader habitat types within a region so that results could be used to predict the nature of surrounding reef areas. Sites were selected using aerial photography, nautical charts, and habitat maps and were verified in the field using a cable mounted video camera. A depth sounder was used to examine the relief or roughness of the seafloor and sampling was then done using SCUBA. Sites within the Flinders and Hamelin regions were approximately 8 to 11 m deep and sites in the Naturaliste and Freycinet regions were 15 to 18 m deep.

Algae

Algae were collected from quadrats of 0.5 x 0.5 m (0.25 m^2) (n = 6 nested within 4 locations in each region) that were randomly stratified on reef. All algae in the quadrat were harvested, sorted to species and wet weighed to determine the composition (number of species and their weight). Algae were identified by experienced algal taxonomists/ecologists (Drs. John Huisman, Julia Phillips and Gary Kendrick) with reference to standard algal identification guides (*e.g.*, Womersley 1984, 1987, 1994, 1996, 1998, 2003). Selected voucher specimens were lodged with the Western Australian Herbarium.

Fishes

Censuses of fishes were done using diver operated stereo videography (DOV). This involves using an underwater stereo-video system comprised of two forward facing video units secured to an aluminium frame (Harvey *et al.* 2001; 2002a). A light emitting diode,

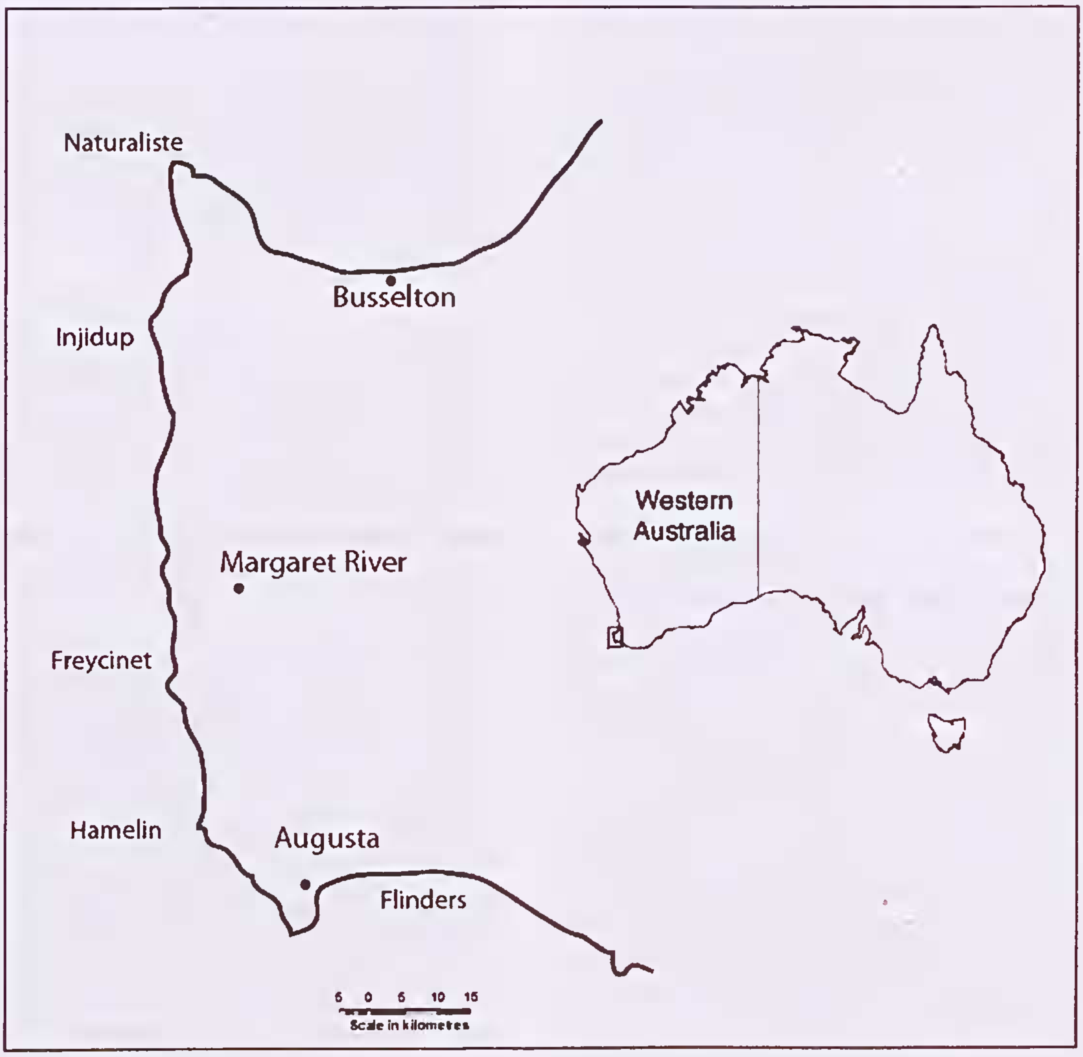

Figure 1. Western Australia and the site locations from this study: Naturaliste, Freycinet, Hamelin and Flinders.

positioned on a rod in front of the cameras, enables the footage to be synchronised when it is viewed on computer. The video units are configured to record the fish from different angles and a computer program is then used to calculate the size of fishes by mathematical triangulation using the two sets of video footage. The video units were swum along replicate underwater transects (75 m long x 5 m high x 5 m wide) by SCUBA divers, and the number of fish per unit area was calculated (n = 4 nested within 4 locations in each region). The transect size was determined from tests that showed high variability at some sites due to low numbers of fishes. Recordings were post processed to identify, count and measure the fork lengths (length from the head to the fork of the tail) of all reef fish seen. Sampling was conducted between 08:00 and 16:00 hours when water visibility was greater than 5 m. The stereo-video system does not fully sample small cryptic fishes, which are most effectively sampled by icthyocides (poisons that kill fish) (Ackerman & Bellwood 2002). This study focuses on non-cryptic reef fish species longer than 40 mm.

The use of stereo video enables conclusive identification of species from the video footage and tests have shown the accuracy of size estimates to be within 2 mm (Harvey *et al.* 2003). Video footage can be stored for long-term comparisons or re-analysis and there is also no bias from different observers who might incorrectly identify fishes of similar species or appearance when underwater.

Censuses of fishes were also undertaken using stereo baited remote underwater video (stereo-BRUV) (Harvey *et al.* 2002b). This method utilises stereo-video units similar to those used for diver operated stereo-video (DOV), however BRUVs were attached to a frame and lowered to the seafloor with a sealed bag of bait in front of the cameras. Video footage was collected to determine the number and size of fishes that visit or inspect the bait. The maximum number of species i at any time t ($MaxNi,t$) was recorded from viewing 45 min duration of footage, and used as a measure of relative abundance between sites. Stereo-BRUV of fishes was conducted at the Cape Naturalise and Injidup regions (Figure 1). For this paper the stereo-BRUV data were specifically used to examine species ranges and compare with documented distributions.

Temperature, substratum, exposure and depth

Water temperature data were sourced from the National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) (2007). These data were derived from the jointly developed AVHRR program where Advanced Very High Resolution Radiometer satellites were deployed to record accurate sea surface temperatures. Coordinates from the AVHRR dataset were selected on the basis of being in close proximity to the study sites and spanned five years, from 2002 to 2006 inclusive. These temperature data provided the study with information on spatial variation in temperature among the four regions. More information on this procedure can be found in Smith (1996).

The NOAA data are sea surface temperatures and water temperature may change with depth. However, Pearce (1997) stated that vertical mixing usually ensures that the temperature of the surface is close to the temperature of the upper few metres of water and generally reflects the subsurface thermal structure. Hemer (2006) described Cape Naturaliste as one the highest energy locations in Australia due to shear bed stress, the LC and storm activity. The region is also subject to average winds of greater than 20 km/h (Bureau of Meteorology, 2008) for every month of the year. These factors would likely provide sufficient mixing of the surface layer to the depths of our sites (< 20 m) such that sea surface temperature data could be assumed to closely represent the water column temperature structure.

Substratum was classified as belonging to one of the following three categories: limestone, granite or a combination of limestone and granite based on observations at the sampling locations and habitat maps (Department of Environment and Conservation, 2006). Exposure of the sites to wave energy was defined as either low, medium or high. This was based on data obtained from Geoscience Australia (2005) and from observations in the field. Water depth was measured in metres.

Patterns of distribution

Broadscale (Western Australia) patterns of distribution of fishes and algae were investigated using known ranges of species and applying these to the species recorded in our surveys. It was inferred that species with tropical or subtropical distributions might not be expected at these latitudes in the absence of the warm LC.

Data on the distributions of fishes were taken from Fishbase (Froese & Pauly 2008), Kuiter (1996), Hutchins & Swainston (2006) and Allen (1997). Fish species were regarded as tropical, subtropical, subtropical-temperate, temperate or widespread (*i.e.*, recorded in a range of climates or widespread across the Indo-Pacific region).

Data on algal distributions were taken from Algaebase (Guiry & Guiry 2008), Womersley (1984, 1987, 1994, 1996, 1998, 2003), Huisman (2000), Huisman & Borowitzka (2003), and Goldberg & Kendrick (2005).

Occurrences of species outside their documented range were also noted and regarded as range extensions or new records for the Capes region. These were determined by comparing our records with the scientific literature and databases.

Regional scale patterns of distribution were examined (*i.e.*, among regions within the Capes) to investigate whether there were differences in species composition of fishes or algae among the regions sampled (Naturaliste, Freycinet, Hamelin and Flinders).

Analyses

Data were analysed using Primer 6 (PRIMER-E Ltd, 2005) to explore trends in the fish and algal assemblages, and relationships with the aforementioned environmental variables; water temperature, mean water depth, substratum type and exposure at each region. A Bray-Curtis dissimilarity matrix was produced using square root transformed data, followed by non-metric multi-dimensional scaling ordination (nMDS) to investigate trends in the composition of fish and algal assemblages. These were overlain with vectors that were based on the correlation between the environmental and the ordination scores and allowed us to infer the degree of influence over the biological data. Pearson correlation coefficients were produced to explore the strength of any observed relationships (Clarke 1993; Clarke & Gorley 2006). Species level data were used to make inferences regarding range distributions and extensions for algal and fish species in the region. ANOSIM (Clarke & Warwick 1994) was used to determine the significance of any clustering of replicates, within regions, in nMDS ordinations.

Results are presented as broadscale patterns of distribution (*i.e.*, the influence of the LC and CC on the Capes region in general) and regional patterns (*i.e.*, an investigation of differences among regions within the Capes region – Naturaliste, Freycinet, Hamelin and Flinders).

Results

Water temperature

Flinders Bay was the most southerly region and had the lowest mean sea water temperature over the five years (18.5°C). In 2004 it was the lowest of all measures at all regions (17.7°C). Mean sea water temperatures were, however, similar among the Naturaliste, Freycinet and Hamelin regions (19.7°C, 19.43°C and 19.4°C

Table 1

Fish species recorded at the Capes using DOV and stereo-BRUV and their distributions (widespread, tropical, subtropical, subtropical temperate, and temperate) based on (Kuiter 1996; Hutchins & Swainston 2006; Froese & Pauly 2008).

Family Widespread	Species	Family Temperate	Species
Aracanidae	*Anoplocapros lenticularis*	Caesioscorpididae	*Caesioscorpis theagenes*
Berycidae	*Centroberyx lineatus*	Cheilodactylidae	*Dactylophora nigricans*
Carangidae	*Pseudocaranx dentex*	Cheilodactylidae	*Nemadactylus valenciennesi*
Heterodontidae	*Heterodontus portusjacksoni*	Dasyatidae	*Dasyatis brevicaudatus*
Kyphosidae	*Kyphosus cornelii*	Dinolestidae	*Dinolestes lewini*
Sillaginidae	*Sillago ciliata*	Enoplosidae	*Enoplosus armatus*
Sparidae	*Chrysophrys auratus*	Gerreidae	*Parequula melbournensis*
Sphyraenidae	*Sphyraena novaehollandiae*	Glaucosomidae	*Glaucosoma hebraicum*
Tropical		Kyphosidae	*Kyphosus sydneyanus*
Haemulidae	*Plectorhinchus flavomaculatus*	Labridae	*Achoerodus gouldii*
Labridae	*Cirrhilabrus temmincki*	Labridae	*Austrolabrus maculatus*
Sub-tropical		Labridae	*Bodianus frenchii*
Labridae	*Choerodon rubescens*	Labridae	*Dotalabrus aurantiacus*
Labridae	*Halichoeres brownfieldi*	Labridae	*Pictilabrus laticlavius*
Sub-tropical – temperate		Labridae	*Pseudolabrus biserialis*
Aplodactylidae	*Aplodactylus westralis*	Monacanthidae	*Meuschenia flavolineata*
Aulopidae	*Aulopus pururissatus*	Monacanthidae	*Meuschenia freycineti*
Berycidae	*Centroberyx gerrardi*	Monacanthidae	*Meuschenia hippocrepis*
Carangidae	*Seriola hippos*	Muraenidae	*Gymnothorax prasinus*
Chaetodontidae	*Chelmonops curiosus*	Muraenidae	*Gymnothorax woodwardi*
Girellidae	*Girella tephraeops*	Odacidae	*Odax acroptilus*
Girellidae	*Girella zebra*	Odacidae	*Odax cyanomelas*
Labridae	*Coris auricularis*	Odacidae	*Siphonognathus beddomei*
Labridae	*Notolabrus parilus*	Pempherididae	*Pempheris multiradiata*
Labridae	*Ophthalmolepis lineolatus*	Plesiopidae	*Trachinops noarlungae*
Monacanthidae	*Meuschenia galii*	Pomacentridae	*Parma victoriae*
Monacanthidae	*Meuschenia venusta*	Rhinobatidae	*Trygonorrhina fasciata*
Mullidae	*Upeneichthys vlamingii*	Scorpididae	*Scorpis aequipinnis*
Myliobatidae	*Myliobatis australis*	Serranidae	*Acanthistius serratus*
Orectolobidae	*Orectolobus hutchinsi*	Serranidae	*Caesioperca rasor*
Pempherididae	*Pempheris klunzingeri*	Serranidae	*Epinephelides armatus*
Platycephalidae	*Platycephalus speculator*	Urolophidae	*Urolophus mucosus*
Plesiopidae	*Paraplesiops meleagris*	Urolophidae	*Urolophus circularis*
Pomacentridae	*Chromis klunzingeri*		
Pomacentridae	*Parma mccullochi*		
Scorpaenidae	*Neosebastes pandus*		
Scorpididae	*Neatypus obliquus*		
Scorpididae	*Scorpis georgianus*		
Scorpididae	*Tilodon sexfasciatum*		
Scyliorhinidae	*Aulohalaelurus labiosus*		
Serranidae	*Callanthias australis*		
Serranidae	*Othos dentex*		
Urolophidae	*Trygonoptera ovalis*		

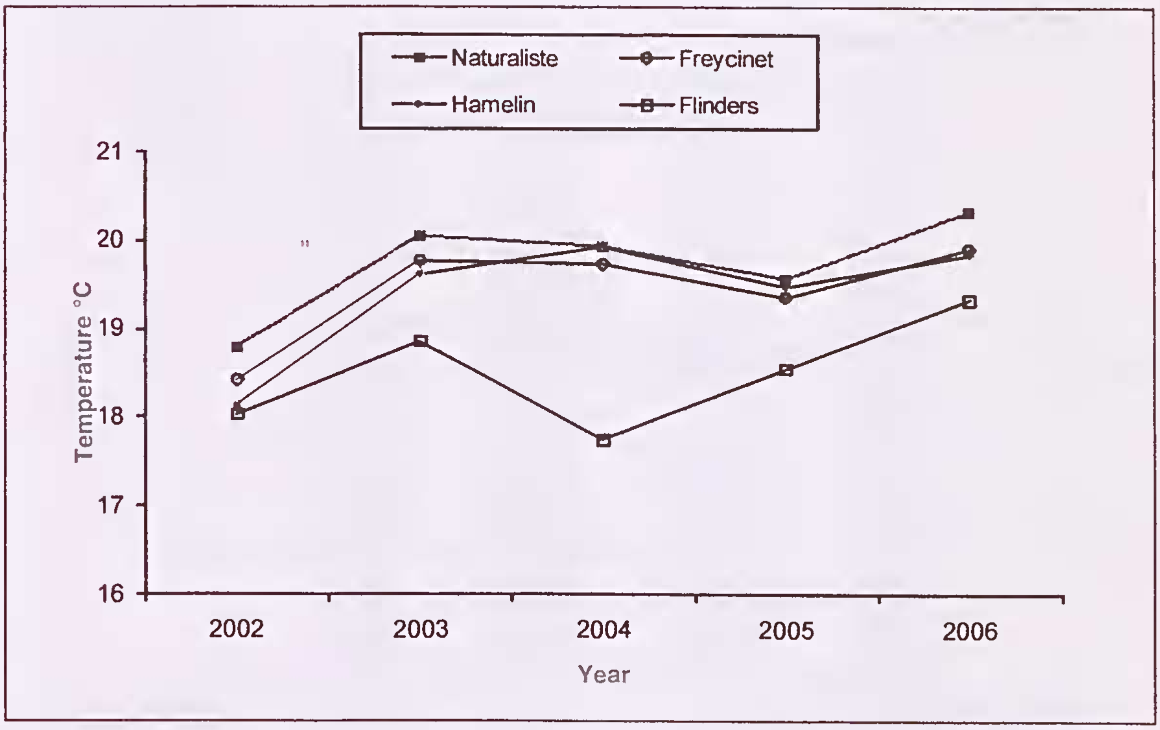

Figure 2. Sea water temperatures from NOAA data (NASA, 2007).

respectively) (Figure 2). The highest annual mean temperature was 20.3°C at Cape Naturaliste in 2006.

Broadscale patterns of distribution

We recorded 73 species of fishes from the DOV and stereo-BRUV throughout the Capes region which belonged to 36 families (Table 1). Based on the distributional classifications (Allen 1997; Froese & Pauly 2008; Hutchins & Swainston 2006; Kuiter 1996) two tropical and one sub-tropical species were recorded. Respectively these were: *Cirrhilabrus temmincki* (Peacock wrasse), *Plectorhinchus flavomaculatus* (gold spotted sweetlips) and *Choerodon rubescens* (baldchin groper). Twenty nine species were regarded as subtropical-temperate, 33 species as temperate and 8 species as widespread (Figure 3).

Cirrhilabrus temmincki is a tropical labrid species that inhabits outer coral reefs (Allen 1997) in waters of 23 to 28° C and is distributed from Japan to the Philippines and northern Australia (Randall 1992). The furthest southern recording is from the Abrolhos Islands (Allen 1997). This species was recorded at Injidup, which is

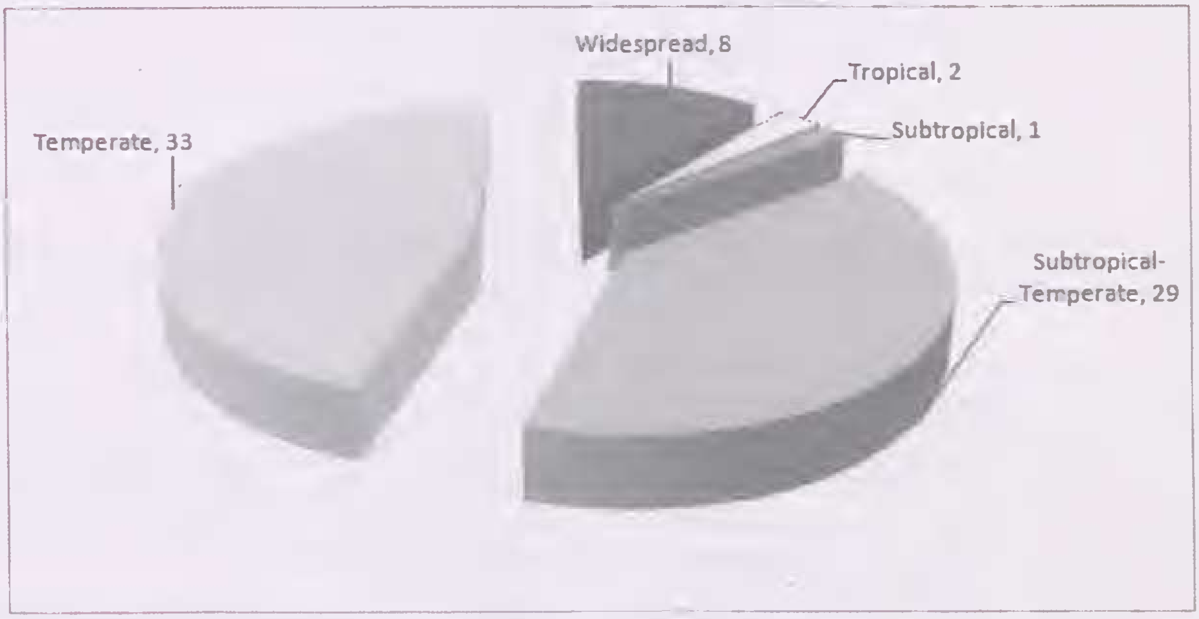

Figure 3. Distributional classification of all fishes recorded in the Capes region using DOV and stereo-BRUV.

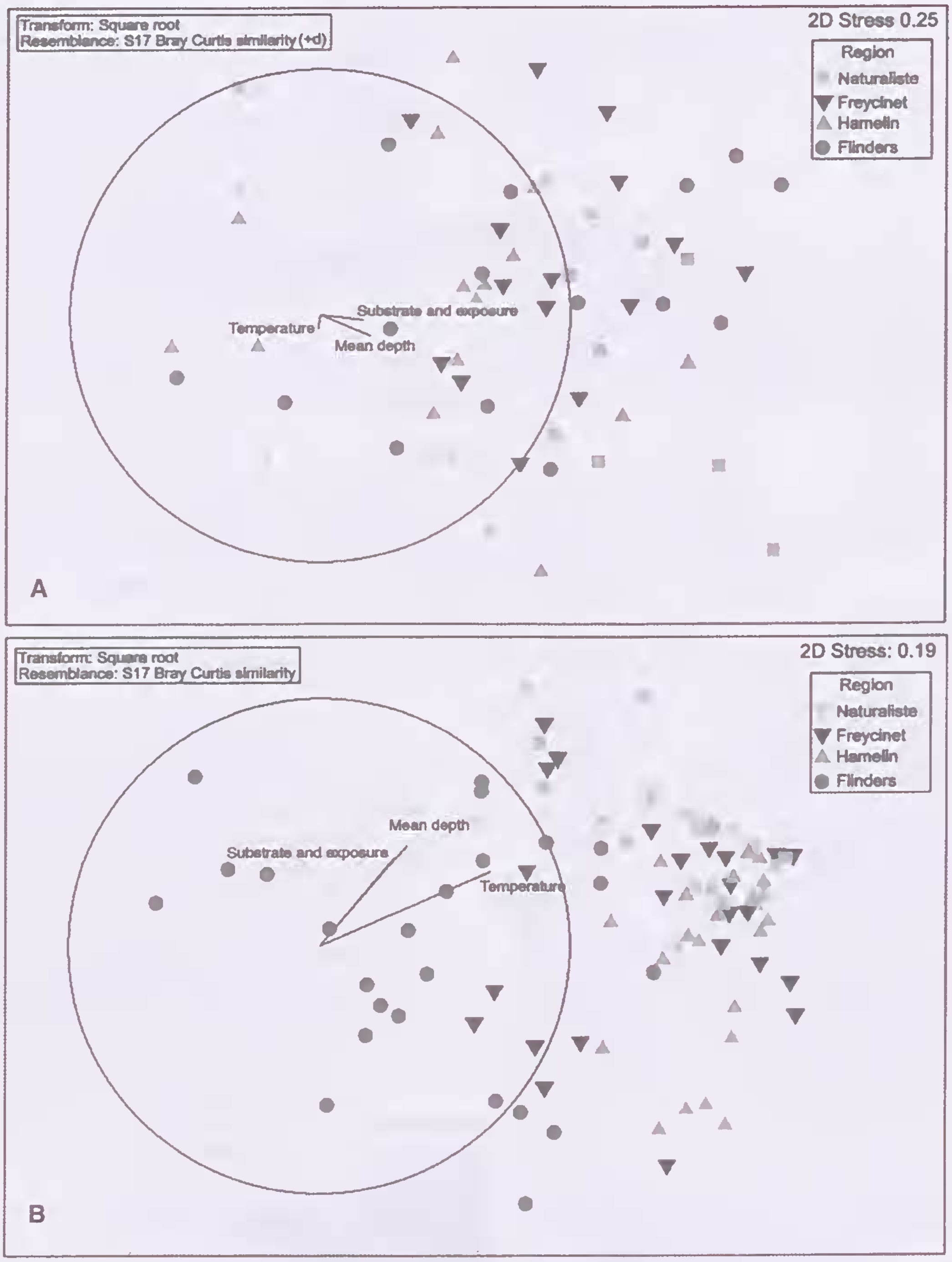

Figure 4. NMDS ordinations based on (A) fish assemblage and (B) algal assemblage structure for each of the sites. Similarity in assemblage composition is represented by the distance between each of the points. Vectors represent each of the environmental variables examined (mean depth, exposure, water temperature and substratum).

approximately 550 km south of the Abrolhos Islands. *Plectorhinchus flavomaculatus* is a tropical species inhabiting coral reefs but is occasionally reported in more southern waters such as Geographe Bay (Hutchins & Swainston 2006) and was recorded at Injidup.

Choerodon rubescens inhabits coral reefs and is occasionally found in the deeper offshore reefs along the lower west coast of WA, with a documented range from Geographe Bay to Coral Bay (Hutchins & Swainston 2006). We recorded this species south of Geographe Bay in stereo-BRUV sampling near Sugarloaf Rock (Cape Naturaliste) and at Injidup.

A total of 205 algal species were recorded in the Capes region, belonging to 49 families. Red algae (Rhodophyta) were the most speciose and accounted for around 68% of all species. Brown (Heterokontophyta) and green (Chlorophyta) algae made up approximately 22% and 10%, respectively.

In terms of biogeographic affinity, all species can be regarded as temperate with the exception of the

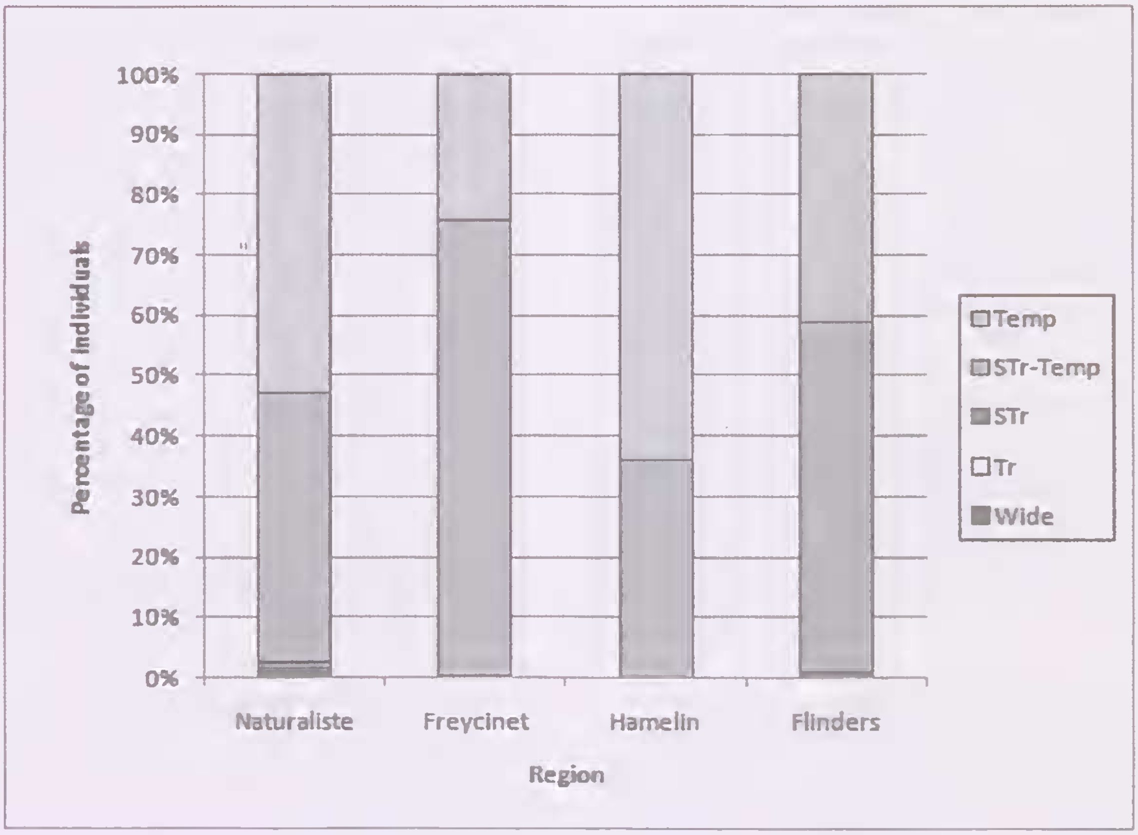

Figure 5. The proportion of fishes in each distributional classification at each region of the Capes. Notes: categories based on (Froese & Pauly 2008; Hutchins & Swainston 2006; Kuiter 1996); Temp – temperate; STr-Temp – subtropical temperate; STr – subtropical; Tr – tropical; Wide – widespread; and tropical sub-tropical species were only recorded at Naturaliste (each 0.3%).

geniculate red alga, *Rhodopeltis borealis*. For this reason, we instead relied on apparent range extensions to provide insight into broadscale patterns of distribution.

Eleven range extensions for algae were recorded during this study. Two of these are southward extensions of the current known range of particular species; the remaining nine are northward or westward extensions (Table 2). *Champia compressa* and *Rhodopeltis borealis* have previously been recorded as far south as Rottnest Island (Huisman 2000), but in this study were found as far south as Flinders Bay and Cape Freycinet, respectively. Northward and/or westward range extensions varied in the distance over which the known range has been extended by this study. *Alleynea bicornis* and *Echinothamnion hookeri*, for example, were previously known as far east as Albany on the southern WA coast (Womersley 2003). Published records for *Codium dimorphum* in Australia are restricted to Tasmania (Womersley 1984); in this study it was found in the Flinders Bay region.

Table 2

Algal range extension (new records) from algal collections in the Capes region.

Range extension	Algal species	Division	Family
Southward	*Champia compressa*	Chlorophyta	Codiaceae
	Rhodopeltis borealis	Rhodophyta	Dumontiaceae
Northward / westward	*Alleynea bicornis*	Rhodophyta	Rhodomelaceae
	Codium dimorphum	Chlorophyta	Codiaceae
	Echinothamnion hookeri	Rhodophyta	Rhodomelaceae
	Mychodea australis	Rhodophyta	Mychodeaceae
	Phyllospora comosa	Heterokontophyta	Seirococcaceae
	Sargassum paradoxum	Heterokontophyta	Sargassaceae
	Sargassum vestitum	Heterokontophyta	Sargassaceae
	Thuretia australasica	Rhodophyta	Dasyaceae
	Zonaria augustata	Heterokontophyta	Dictyotaceae

Regional scale patterns of distribution

There were no obvious patterns in the fish assemblage structure among the four regions (Naturaliste, Freycinet, Hamelin and Flinders) in nMDS ordinations and this was supported by a non-significant ANOSIM result (R – value 0.014, sig 25%). Water depth was the most influential of environmental variables on species composition, rather than water temperature, exposure or substratum (Figure 4). Regions with warmer waters did not have higher abundances of fishes of tropical, subtropical or subtropical-temperate origin (Figure 5).

There was a pattern in algal assemblage structure among regions according to nMDS with Flinders region separating from the other regions on the west coast (Naturaliste, Freycinet and Hamelin). Water temperature was the most influential of environmental variables, relative to exposure, substratum and depth (Figure 4). This was supported by a modest to strong Pearson correlation (Fowler & Cohen 1990) between algae and water temperature (R = 0.699) that was higher than Pearson R-values for other environmental variables (Table 3).

Table 3

Pearson correlations (R - values) between the biological and environmental variables examined.

	Mean depth	Exposure	Water temperature	Substratum
Algae	0.376	0.320	0.699	0.320
Fish	0.199	0.168	-0.011	0.168

On the west coast (Naturaliste, Freycinet and Hamelin regions), *Ecklonia radiata*, *Scytothalia dorycarpa* and *Platythalia quercifolia* dominated the macroalgae, whereas in the Flinders Bay region *Scytothalia dorycarpa*, *Kuetzingia canaliculata* and *Cystophora grevillei* were dominant. Some understorey species such as *Amphiroa anceps*, *Pterocladia lucida* and *Curdiea obesa* were found in all regions.

When comparing algal species distributions and richness among regions, Hamelin and Freycinet regions were combined (and referred to as Hamelin) due to their close proximity and the considerable overlap in algal assemblages found in each region (Figure 4). Species richness increased moving south, and twice as many algal species were recorded in the Flinders region compared to the Naturaliste region (Figure 6). Forty-four out of 205 species, representing around 21%, were common to all regions, while 41.5% were found in only one region which indicates a moderate degree of geographic distinctness. Around 25% of algae recorded from the Flinders region were 'endemic' to that region (in the context of this study), which was higher than either the Hamelin (11%) or Naturaliste (6%) (Figure 6).

Discussion

The interaction of the Leeuwin and Capes Currents creates unusual environmental conditions in the Capes region of Western Australia. As a likely effect of the warm southward flowing waters of the LC mixing with the CC, the flora and fauna inhabiting the region show overlap between two biogeographic zones; the Central West Province and the Southern Province. This has been

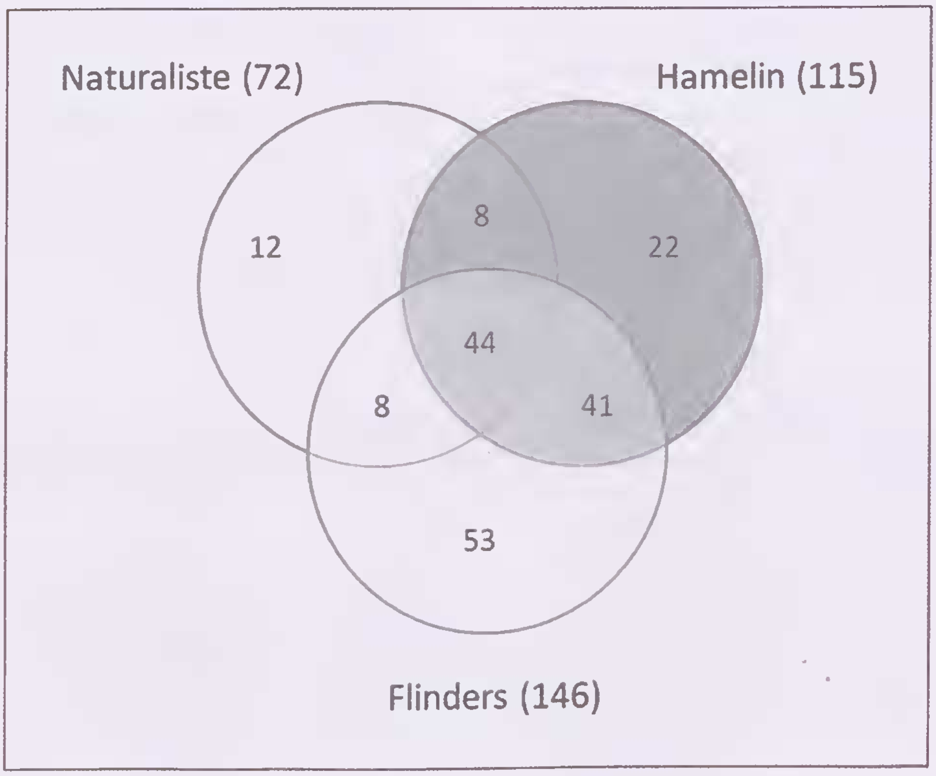

Figure 6. Venn diagram of the distribution of algal species among the regions. Note that Hamelin and Freycinet regions were combined into one grouping (Hamelin) in this analysis. Numbers in parentheses are the total number of species found within a region.

recognised in the Integrated Marine and Coastal Regionalisation of Australia with the designation of the Southwest Transition (Commonwealth of Australia, 2006) which encompasses the Capes region. This transition is reflected in the organisms inhabiting the Capes waters, with tropical and sub-tropical fish species identified in this and other studies, as well as range extensions of a number of algal species. A transition zone of 23° to 35°S was also suggested by Hutchins (1991) when describing the influence of the LC on fish species.

This study has used biological data from an existing project in the Capes region correlated with physical structuring variables to investigate the potential role of the LC, and in particular water temperature, on the fish and algal assemblages of the Capes region. Data have also been introduced from other studies on the effects of the LC on fishes and algae.

Scales of effect

In terms of broadscale distributions of species, the data indicate a number of fish species that are outside their generally accepted range. That is, species were encountered that would normally be expected in more tropical marine environments than the 33 to 34° S latitude of the Capes region. Forty six percent of fish species recorded were regarded as tropical, subtropical or sub-tropical – temperate. These results and the findings of other studies (Ayvazian & Hyndes 1995; Hutchins 1991), support the classification of the Capes region as part of the aforementioned transition zone between tropical and temperate waters.

The work of Hutchins (1991) indicates that the impact of the LC on shallow marine reef fishes in the Capes region is less than that at Rottnest Island, which may be expected given the more southward location of the Capes region and the cooler waters. Hutchins recorded 61 species of reef related tropical fishes at Rottnest Island and four in the Capes region.

The mean SST recorded in the Capes region from the NOAA data (NASA, 2007) was 19.26°C. This compares with the SST at Cape Mentelle (also in the Capes region) of 19.25°C (Pearce & Pattiaratchi 1999). Mean SST further north, where the LC also been linked to the structure of marine biotic assemblages, range from 26°C at Ningaloo (Westera 2003; Sleeman *et al.* 2007), 22°C at the Houtman Abrolhos Islands (Pearce 1997) and 21°C at Rottnest Island (Pearce & Faskel 2001). The decrease in water temperature with increasing latitude is consistent with the lower numbers of species of tropical or subtropical origins.

The small number of southward range extensions noted for algal species suggests that the LC does not strongly influence the distribution of algae in the regions studied. Phillips (2001) contends that the LC has definitely had an influence on extending the range of tropical species to the southern coasts of WA. However, the CC may obstruct southward dispersal along the coast (Wernberg *et al.* 2003) since it flows northwards and hence counters the LC. In this study, all algae recorded except for one species (*Rhodopeltis borealis*) have what could be considered a temperate distribution. While it is likely that tropical algae are carried southwards by the LC during years of strong flow, they probably establish as isolated populations (Phillips 2001) and as such may not be regularly encountered. The combined effects of the LC and the CC creates a very large transition zone between tropical and temperate floras (Wernberg *et al.* 2003).

Northward or westward range extensions were more common among the algae recorded in this study. While this may be partly attributed to algal spore dispersal by the northerly flowing CC, it is likely to also be largely due to the relatively few algal collections from the Capes region. The Flinders and Freycinet regions, in particular, have had little attention prior to this study in terms of the algal flora.

Variability was noted at a regional scale (within the Capes region) in terms of differences in algal (but not fish) assemblages. Regions on the west coast of the Capes that experience warmer waters were different to those in Flinders Bay further south. However the west coast sites are more exposed to wave and storm activity. Sites at the Hamelin region were of a similar depth to Flinders (10 m) but the Freycinet and Naturaliste regions were deeper (15–18 m) which may also have influenced the observed differences.

Smaller scales of effect on marine communities of the Capes are also likely, driven by depth, substratum type and exposure. These all showed weak Pearson correlations with the algal assemblages. Other factors not examined in this study that would likely influence the marine biota are topographic complexity, light to the benthos and sediment cover (Harman *et al.* 2003; Kendrick *et al.* 2004; Harvey 2005; Wernberg *et al.* 2005; Toohey 2007).

Larval transport

The distributions for some of the fish and algal species in this study may be influenced by changes in water temperatures resulting from the flow of the Leeuwin and Capes Currents, but may also be due to the physical transport of propagules from the warmer northern and cooler southern areas. Although algal propagules have been demonstrated to mostly settle within a short distance of the parent (Hoffmann 1987), currents have been shown to transport drift algae over long distances, particularly positively buoyant species such as *Sargassum* and their associated epiphytes (Womersley 1987; Walker 1991). Walker (1991) hypothesised that although the potential for the LC to transport algal propagules is reduced in comparison to faunal larvae, there is the potential for drift algal dispersal to extend the range of algal species. Goldberg *et al.* (2004) also reported limited dispersal of algal propagules with the species richness of algal canopy assemblages being maintained locally at the Recherche Archipelago, on the south coast of Australia.

The LC is, however, capable of transporting tropical fish eggs and larvae in a southwards direction and has the potential to extend the range limits of these species (Hutchins 1991). The effect of the LC on fish recruitment is strongly identifiable by comparing the south-east and south-west coasts of Australia. In south-east Australia, transport of fish propagules occurs in summer, whereas southerly transport in south-west Australia occurs in winter with the strongest flow of the LC. The timing of transport is more favourable to larval recruitment on the east coast as it coincides with the breeding period of most tropical fish (Hutchins 1991), whereas the southerly transport by the LC in the winter months, when water temperatures are falling and fish breeding is limited, is likely to create conditions where only the hardiest of fish larvae are likely to survive and recruit (Hutchins 1991).

Diversity

The number of fish species recorded in these surveys is comparable with other surveys of fishes in temperate Western Australia. In the Recherche Archipelago a study using DOV techniques recorded 90 species of fishes, many in common with the Capes surveys (Harvey 2005; Harvey *et al.* 2005). The Capes region does, however, distinguish itself through the high fish endemism characteristic of the south west coast. Fox & Beckley (2005) (p 403) stated that the south west coast was an endemism 'hotspot' when compared to other regions along the west Australian coastline.

The number of algal species recorded in this survey (205 species) was comparable with other studies on the temperate Western Australian coast (Table 4). The consistently high species richness from Jurien to the Recherche Archipelago may be due to the LC.

Water temperature within the Capes region may be one factor influencing marine assemblages within the region, but habitat is likely to be equally important. Relief and rugosity of substratum have not been evaluated here but are likely to provide further explanation of differences among regions. It is likely that the diversity of habitats in the region exerts a stronger role in shaping species assemblages on a regional scale (*i.e.*, within the Capes region) than the effects of the Leeuwin and Capes Currents.

This study was not originally intended to investigate the effects of the LC on marine biotic assemblages of the Capes region. However, the data indicate a broadscale effect of the LC on the Capes region in terms of the number of tropical, subtropical and particularly subtropical-temperate fish species recorded. This is consistent with other studies (Hutchins 1991; Lenanton *et al.* 1991; Ayvazian & Hyndes 1995) that showed an effect of the LC on the distribution of fish species. In the future, human induced climate change is also expected to lead more southerly distributions of marine biota on the West coast of Australia (Greenstein & Pandolfi 2008).

Table 4

Algal species richness at locations from the Western Australian coast for comparison with the Capes region.

Location	Species richness	Reference
Capes (Geographe Bay to Flinders Bay)	205	This project
Jurien	280	(Keesing & Hine 2005)
Geographe Bay (Quarries to Bunbury)	243	(Keesing & Hine 2005)
Perth metropolitan coast	229	(Keesing & Hine 2005)
Marmion Marine Park	202	(Simpson & Ottaway, 1987)
Marmion Marine Park	152	(Wernberg *et al.* 2003)
Recherché Archipelago	240	(Goldberg & Kendrick, 2005)

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